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ABSTRACT

This booklet describes the history of the space shuttle, especially after the Challenger accident. Topics include: (1) "Introduction"; (2) "Return to Flight: The Recovery"; (3) "Space Shuttle Chronology"; (4) "Examples of Other Modifications on Shuttle's Major Systems"; (5) "Space Shuttle Recovery Chronology"; (6) "Poised for Launch: Space Shuttle and Crew"; (7) "Versatile Achievements: The First Twenty-Four Flights"; (8) "Selected Space Shuttle Mission Achievements and Firsts"; and (9) "The Space Shuttle into the 21st Century." (YP)

Space Shuttle

The Renewed Promise


USA

Space Shuttle

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Space Shuttle:

The Renewed Promise

By
Neil McAleer

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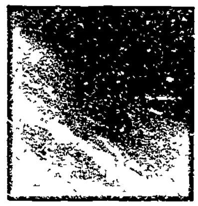

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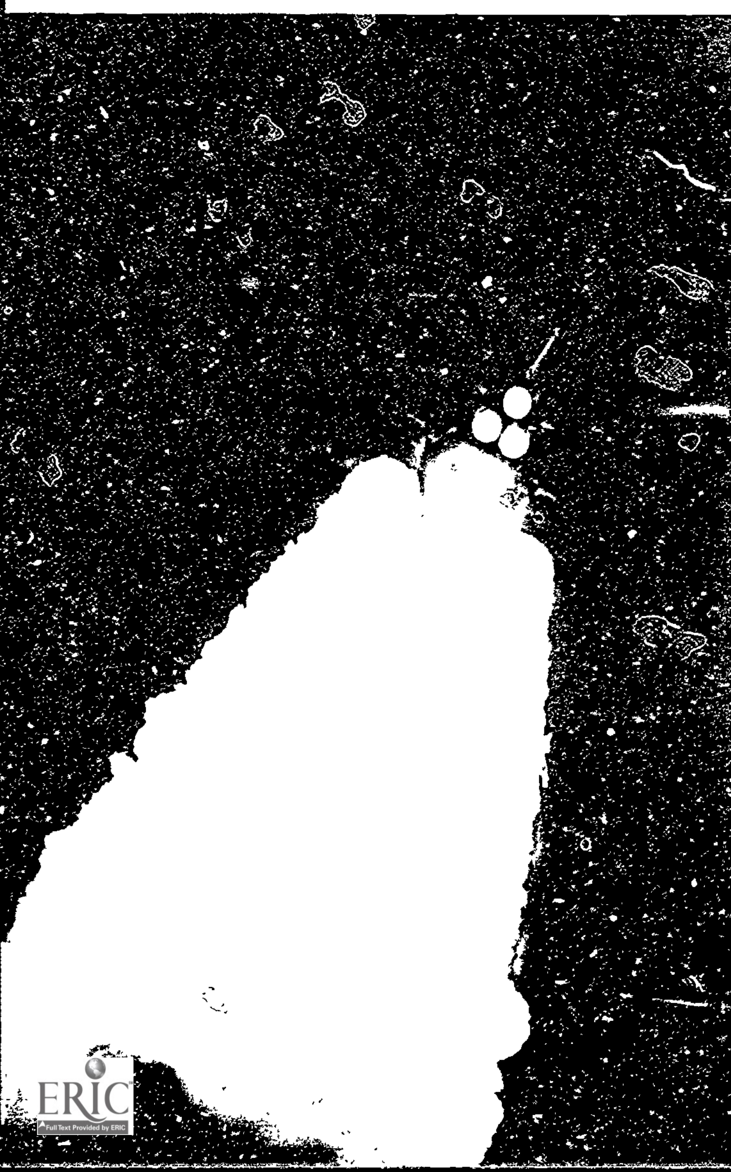
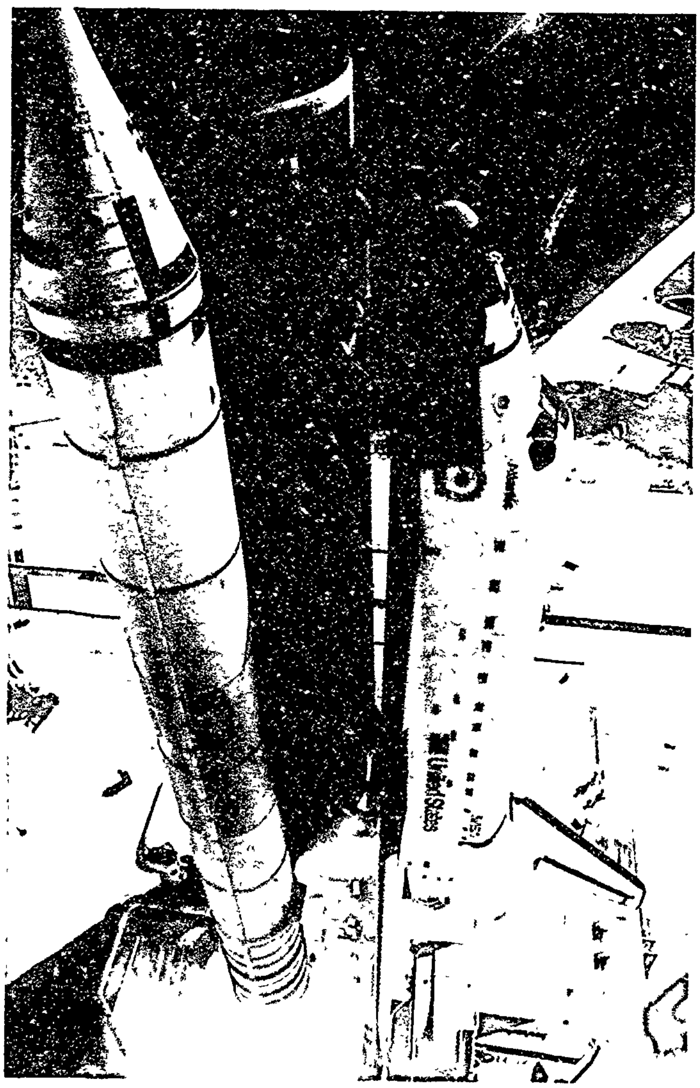




There can be no thought of finishing, for "aiming at the stars," both literally and figuratively, is a problem to occupy generations...

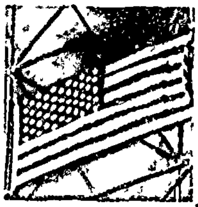
☐ Dr. Robert H. Goddard

When the Space Shuttle flew again in September 1988, it remained the most sophisticated, complex and technologically advanced manned spaceship in the world. America's intensive return-to-flight effort over two-and-a-half years since the Challenger accident included hardware redesign and upgradings, rigorous testing programs, detailed reviews of the entire Shuttle system, and improvements in safety procedures and decision-making processes. The Shuttle became a safer spacecraft during the recovery period, but veteran astronauts and engineers alike know that sending men and women into the space frontier will continue to involve risk, just as it has since America's first manned suborbital flights in 1961.

During the 1960s, several studies of a reusable manned spacecraft were conducted. Then in April 1969, NASA's Space Shuttle Task Group was established–just months before the flight of Apollo 11 when two men walked on the Moon for the first time in human history. In January 1972, as the last two Apollo missions (16 and 17) prepared to fly to the Moon, President Nixon announced that the nation would proceed with the Space Shuttle.

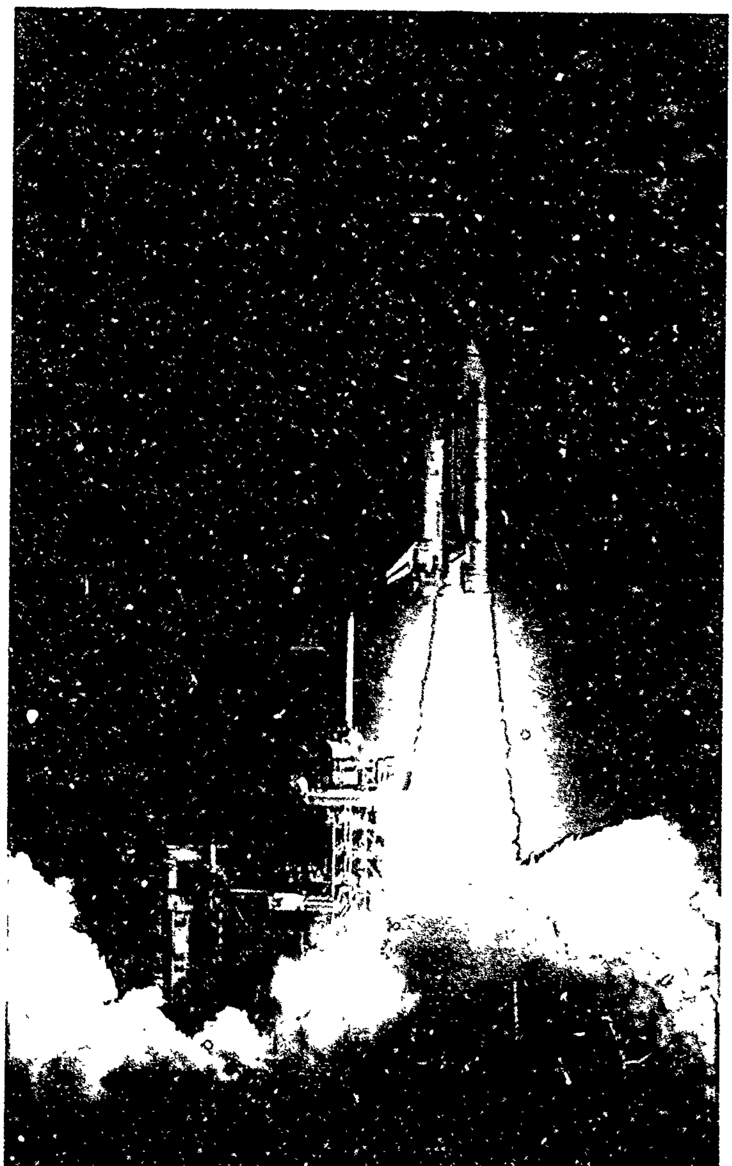
The United States developed the Space Shuttle system to greatly improve its access to space, and for almost five years, during which 24 successful missions were flown, the Shuttle did just that.

There were as many Shuttle flights flown in five years as there were manned Mercury, Gemini, and Apollo flights flown in ten years. The Shuttles also carried twice the number of astronauts during half the time period. By that measure, the Space Shuttle fulfilled its goal of improving access to space.



Return to Flight

The Recovery



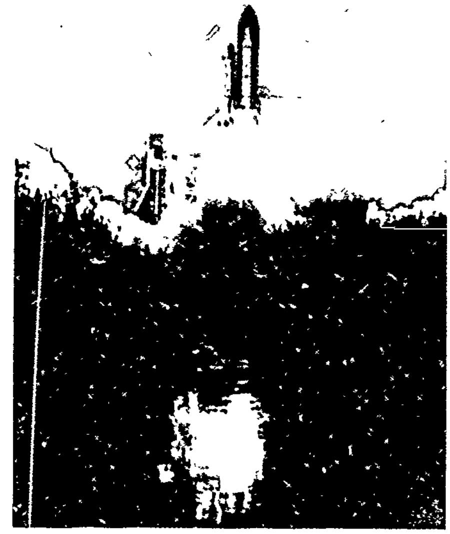
In early February 1986, as the nation mourned the tragic loss of seven Americans and the *Challenger* spaceship, President Reagan announced the creation of the Presidential Commission on the Space Shuttle *Challenger* Accident. Chaired by William P. Rogers, former secretary of state, it became known as the Rogers Commission. NASA's 51-L Data and Design Analysis Task Force was also established at this time to support the work of the Rogers Commission.

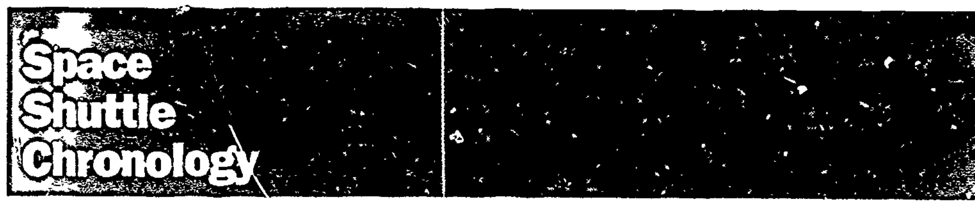
More than 6,000 people were involved in the commission's four-month investigation of the accident, and some 15,000 pages of transcript were taken during public and closed hearings.

The Report of the Presidential Commission on the Space Shuttle Challenger Accident

The commission's report was published and delivered to the President on June 6, 1986. Hardware redesign of the faulty solid rocket motor joints and a review of the Space Shuttle management structure were two of the nine basic recommendations set forth. The other seven recommendations covered: critical hardware review and hazard analysis, safety organization, improved communications, landing safety, launch abort and crew escape; flight rate; and maintenance safeguards. These recommendations represented the guidelines for the enormous amount of work to be done by NASA and the aerospace community to return the Space Shuttle to flight status. The commission also requested that a progress report on implementing the recommendations be made to the President in one year, which was delivered in June 1987.

Left:
Space Shuttle *Columbia* leaves Earth for the first orbital mission on April 12, 1981. Veteran astronaut John Young, Commander, and Pilot Robert Crippen tested the Space Shuttle's systems in space for the first time.
Right:
Discovery takes off in April 1985. While in orbit, it deployed two communications satellites. Among the seven crew members were U.S. Senator "Jake" Garn and Charles Walker, a payload specialist from industry.





February 1964 to October 1968	Several studies of an Integral Launch and Reentry Vehicle conducted
April 1969	NASA's Space Shuttle Task Group established
February 1970	NASA creates Space Shuttle Program Office
January 1972	President Nixon announces intention to proceed with Space Shuttle
March 1972	NASA selects basic Shuttle configuration (orbiter, main engines, external tank, and solid rocket boosters) of today's system
July 1972	NASA announces selection of Rockwell International as prime contractor for Space Shuttle
June 1974	Rockwell International starts assembly of crew module for Space Shuttle *Enterprise*, the first orbiter, which was used for approach and landing tests
September 1976	Roll out of first Space Shuttle orbiter, the *Enterprise*
August 1977	First of 5 approach and landing tests; *Enterprise* released from Boeing 747 at 6705.6 meters (22,000 feet)
April 1981	Space Shuttle *Columbia* makes first of four orbital flight tests; Commander John Young and Pilot Robert Crippen at the controls
November 1982	*Columbia* flies the first Shuttle flight (STS-5) in which commercial satellites (two) are deployed
April 1983 to January 18, 1986	Nineteen more successful flights of the four Space Shuttle orbiters, for a total of more than 2,400 orbits around the Earth and accumulated mileage of some 91,732,608 kilometers (57 million miles) - a distance equal to more than 118 round trips to the Moon
January 28, 1986	After 73 seconds of flight, the *Challenger* is lost, claiming 7 crew members and spaceship
February 1986	Two-and-one-half year recovery effort begins with formation of the Presidential Commission on the Space Shuttle Challenger Accident; establishment of 51-L Data and Design Analysis Task Force
September/ October 1988	Space Shuttle *Discovery* successfully flies the first mission (STS-26) since the *Challenger* accident; the U.S. manned space program is back in business

Examples of other modifications on Shuttle's major systems

Solid Rocket Booster

- Redesign and improvement of the aft external tank attach ring on the solid rocket booster to make the ring stronger and better distribute the loads encountered. It now wraps completely around the solid rocket case, whereas before the ring only went around three-quarters of the rocket case.
- Structurally strengthening the aft skirt on the solid rocket boosters by such measures as upgrading bolts and adding brackets

The Orbiter

- Brake stators thickened
- Main landing gear axles stiffened
- Tire pressure monitored
- New brake orifices used
- Crew escape system added (telescoping pole and blow-out hatch)
- 17-inch disconnect latch modified
- Gaseous oxygen flow control valve redesigned

The Main Engine

- External plating added to chamber outlet neck
- Structural housing improvement on main fuel valve
- Turbopump turbine blades strengthened
- Hot gas sensor improved
- Coolant circuit modified

External Tank

- Hydrogen pressurization line strengthened
- Freezer wrap added to the hydrogen line to permit visual detection of a hydrogen fire

Redesign of the Solid Rocket Booster Joints

A preliminary review of the redesign work on the solid booster was conducted in September 1986 and a baseline design was established. Hundreds of subscale tests were run on laboratory devices and smaller motors to test different sealing materials, check for leaks, and generally gain a complete and in-depth understanding of the motor and its parts. A year later, in August 1987, the first of five full-scale, full-duration test firings was conducted.

The design changes in the solid rocket motor were made, eliminating the flaw that led to the accident. The engineering changes included: tighter fitting joints with a new capture latch that controls movement between the tang and clevis of the field joints (those segment joints mated at the Kennedy Space Center, Fla., and not at the factory); an addition of a third O-ring, bonded field-joint insulation, heater bands with weather seals for all three field joints that keep the O-ring areas at a minimum of 23.8 degrees Celsius (75 degrees Fahrenheit) for increased resiliency, and a new radially bolted design, using 100 bolts and heat-shielding material, for the lowest joint on the solid booster rockets—the case-to-nozzle joint above the exhaust flame.

Beyond the redesign of the field joints, improvements were made in the factory joints, rocket nozzles, the igniter chamber, and the ground-support equipment and procedures that assemble the rocket segments. All these activities were scrutinized by a special oversight panel of the National Research Council.

Other Hardware Modifications

During the two-and-a-half years that the Shuttle fleet was grounded, hundreds of other modifications, some major, some minor (many of which were planned before the accident) were incorporated into the Shuttle system. The main engines underwent the most aggressive ground-testing program in their

Right: The first of five full-scale, full-duration tests of the new solid rocket motor design took place in Utah on August 30, 1987. Hundreds of subscale tests were also run on smaller motors as part of the intensive return to flight effort

history, equivalent in operational time to more than 36 missions. All engine improvements were certified to demonstrate improved reliability and operating safety margins, and they have been incorporated into the engines which will be used on *Discovery*, *Columbia*, *Atlantis*, and OV-105, the replacement orbiter that will be ready to fly in the early 1990s.

Additional safety margins were established by thoroughly testing hardware and often forcing failures on the ground to establish safety and reliability limits. A conservative and rigorous ground test program should not be "safe" to achieve a safe flight program; the risks should be taken on the ground, not on the way to orbit.

Examples of the major modifications made during the return-to-flight period appear in the table above left.

Centralized Safety

NASA's safety programs were completely reorganized as a result of another Rogers Commission recommendation. The Office of Safety, Reliability, Maintainability, and Quality Assurance was established in 1986, and it now has direct authority for safety and related quality controls for all NASA operations. Today more people are assigned to safety and related programs, improved communications have been initiated, and the review system for compliance to new procedures is rigorous and well defined.

The new Office of Safety ensures that the highest levels of NASA's management team are aware of safety issues. Responsible for aggressive oversight, the office sets policy, establishes procedures, and then ensures that policies and procedures are followed for the projects. The goal is nothing less than 100-percent success.

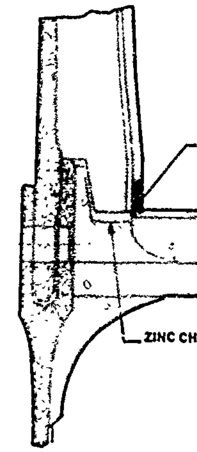
Another major task directly relating to safety was a series of comprehensive reviews of critical flight hardware, software, and systems, their possible failures, and the consequences of such failures for all major Space Shuttle components (orbiter, external tank, solid rocket booster, and the main engines). The reviews were initiated in March 1986 and several review teams were formed. An ongoing process, the goal is to identify hardware designs in all Space Shuttle systems that may require improvement. A special committee of the National Research Council was responsible for verifying the adequacy of the effort and reported directly to the NASA Administrator.

Bailout Crew Escape

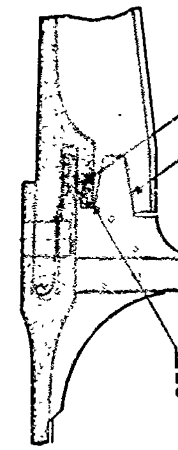
Another recommendation of the Presidential Commission called for a crew escape system that could be used during the controlled gliding portions of the flight—a relatively narrow segment of a flight profile between 1,524 and 6,096 meters (5,000 and 20,000 feet) in altitude and a maximum velocity of 370.1 kilometers per hour (230 miles per hour). Such a system cannot be used, however, during the first stage powered flight when the solid rocket boosters are firing. It is not designed to save the crew in a situation like the *Challenger* accident.

Testing and evaluation of two escape systems began in November 1987. One system used tractor rockets to propel crew members, one at a time, out of the side hatch in the orbiter's mid-deck. The other system tested used a telescoping pole – about 3.2 meters (10.5 feet) in length – onto which the crew members attach a lanyard and slide down and off to clear the orbiter wing and open a parachute. The pole, made of lightweight

Field Joint Metal and Insulation



Original Design



New Design

The original and new designs of the field joints on the solid rocket booster are compared here. The new design included tighter-fitting joints with a capture latch, a third O-ring, and heater bands for the field joints.

From a C-141 aircraft, a Navy parachutist tests the escape system that Shuttle crews can use during controlled gliding portions of the flight (between 1,524 and 6,096 meters [5,000 and 20,000 feet] from the ground). Astronauts will attach a lanyard and slide down the telescoping pole to clear the orbiter and open a parachute.

aluminum and steel, is attached to the mid-deck ceiling. Both systems were tested and evaluated for a crew of up to eight.

A decision was made in April 1988 to outfit the orbiters with the telescoping pole system because it would be safer and simpler to operate and easier to maintain than the tractor rocket system. If a Space Shuttle ever had to ditch in the ocean, the crew could bail out using the telescoping pole because structural analysis of an orbiter landing on water has shown it to be extremely hazardous.

The Mixed Fleet

One of the most far-reaching recommendations of the presidential commission concerns the Space Shuttle's flight rate. Because the United States had relied heavily on the Space Shuttle as its principal launch vehicle, the commission concluded that this reliance created a "relentless pressure" to increase the launch rate which, in turn, contributed to the accident.

In August 1986, two months after President Reagan received the commission's report, he announced that, except for satellites exclusively requiring a Shuttle launch or requiring it for national security or foreign policy reasons, NASA would no longer launch commercial satellites.

This decision eventually led to the mixed-fleet concept, which shifted some of the Space Shuttle launch burden to unmanned expendable launch vehicles, which are used only once. Many Department of Defense launches originally scheduled on the Space Shuttle, for example, are now rescheduled on the expendable *Titan IV*, which has a payload capacity about equal to the Shuttle. The military will also use their medium launch vehicles for some of the smaller satellites originally scheduled to fly on the Shuttle.

Meeting the expanding launch needs of the United States with a mixed fleet of launch systems has several important benefits. First, the nation's access to space will be less vulnerable to a single failure or logistics problem. In addition, each payload can be mission-matched to either the Space Shuttle or an expendable. This will leave the Shuttle to fly those missions for which it is uniquely suited such as dedicated life-science flights and other scientific missions requiring the hands-on attention of researchers and specialists.

The Replacement Orbiter

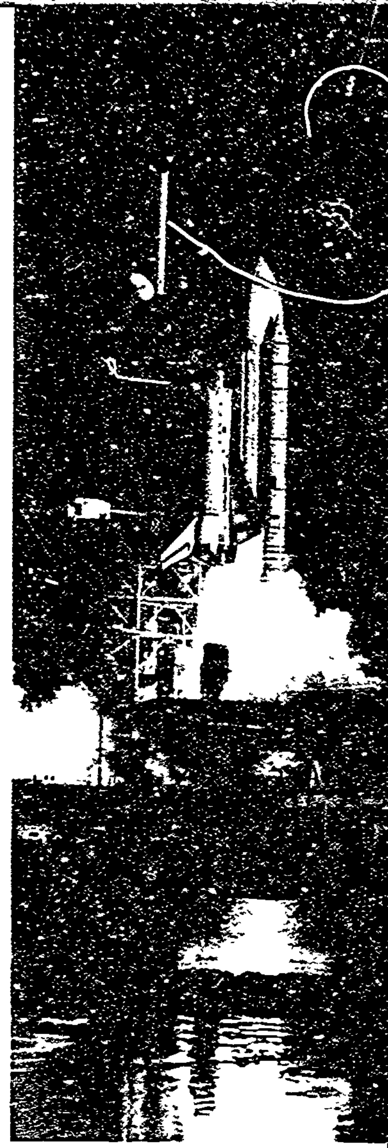
The decision to build a replacement orbiter to expand the Shuttle fleet to four vehicles was made in August 1986. By the following July, negotiations were completed with Rockwell International to build OV-105, and the company began construction in August 1987. Orbiter OV-105, basically identical to *Discovery* and *Atlantis*, is planned for completion in 1991. It is scheduled to fly its maiden mission in 1992.

In March 1988, NASA announced its Orbiter-Naming Program for the replacement orbiter, an educational project planned so that students in grades K through 12 could actively participate in naming the new Space Shuttle. Said NASA Administrator, Dr. James C. Fletcher during the announcement, "It is fitting that students and teachers, who shared in the loss of the Space Shuttle *Challenger*, share in the creation of the replacement."

When the new orbiter finally blasts skyward in the early 1990s as the fourth ship in the fleet, the U.S. space program will receive another surge of momentum as it approaches the year 2000 and the first full century of the Space Age.

Space Shuttle Recovery Chronology

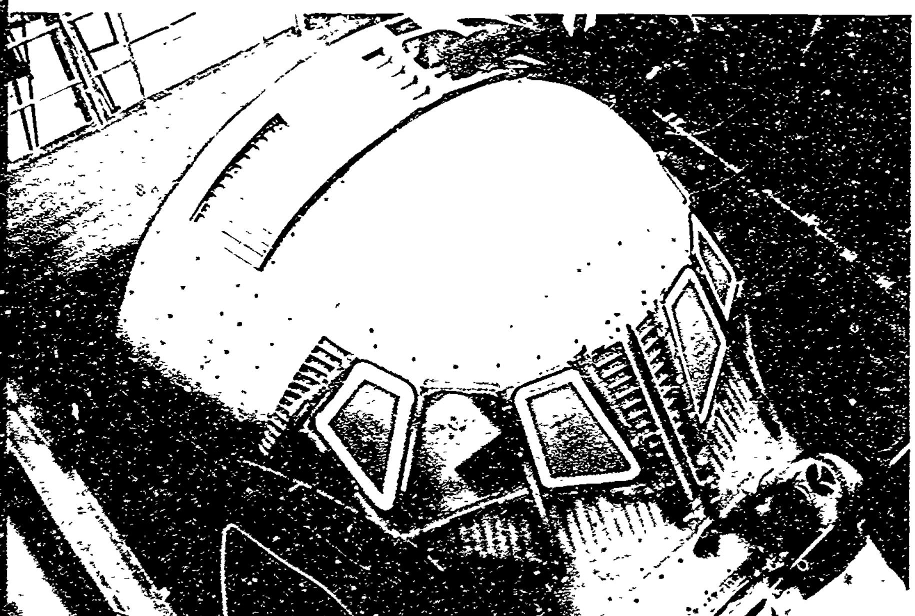
January 28, 1986	*Challenger* accident; loss of ship and crew
February 1986	Formation of Presidential Commission on the Space Shuttle *Challenger* Accident; NASA establishes 51-L Data and Design Analysis Task Force
March 1986	Solid Rocket Motor Redesign Team formed
June 1986	*Report of Presidential Commission on Space Shuttle* Challenger *Accident* submitted to President, including 9 recommendations
July 1986	NASA creates new Office of Safety, Reliability, Maintainability and Quality Assurance
October 1986	The Committee on Science and Technology, U.S. House of Representatives, released its report, *Investigation of the* Challenger *Accident*
January 1987	Flight crew selected for first Space Shuttle mission (STS-26) after accident
June 1987	NASA's report, "Implementation of the Recommendations" submitted to President Reagan
August 1987	First of five full-scale, full-duration test firings of the redesigned Space Shuttle solid rocket motor
October 1987	NASA issues first mixed-fleet manifest for Space Shuttle missions and expendable launch vehicles
November 1987	Testing begins on escape system that could be activated during controlled gliding flight only
September 1988	Space Shuttle *Discovery* is ready for first U.S. manned spaceflight (STS-26) since the *Challenger* accident



Space Shuttle *Columbia* leaves Earth for the first orbital mission on April 12, 1981.

Poised for Launch

Space Shuttle and Crew



The crew module for the new Space Shuttle orbiter being built by Rockwell International at their Downey, CA, plant. This will be the pressurized living quarters for mission crews above the Earth when the vehicle begins flying in the early 1990s

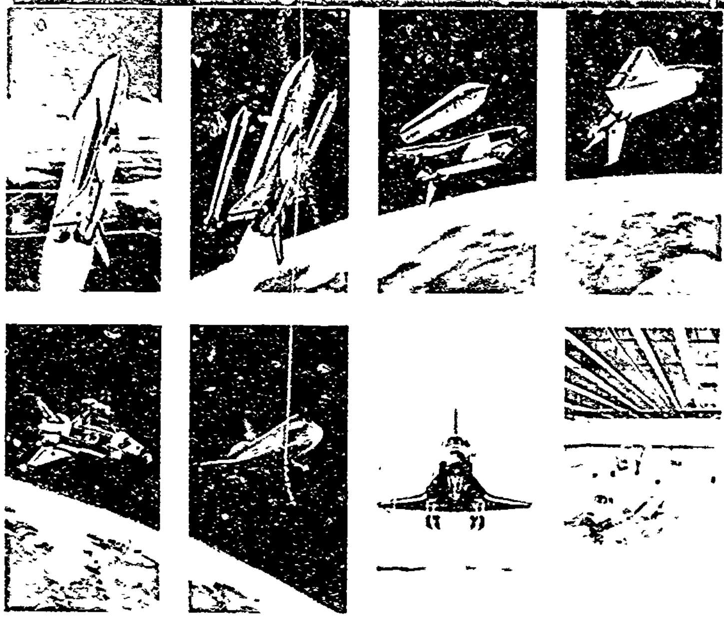
The Space Shuttle system remains the most technologically advanced and complex machine on planet Earth. NASA has never estimated even a ballpark total for the millions of parts that comprise its launch configuration.

The major components are. the orbiter spacecraft, the three main engines, with a combined thrust of almost 544,311 kilograms (1.2 million pounds), the huge external tank (ET) that feeds the liquid hydrogen fuel and liquid oxygen oxidizer to the three main engines; and the two solid rocket boosters (SRBs), with their combined thrust of some 2,630,836 kilograms (5.8 million pounds). which provide most of the power for the first two minutes of flight. The SRBs take the Space Shuttle to an altitude of 45.06 kilometers (28 miles) and a speed of 4,973 kilometers per hour (3,094 miles per hour) before they separate and fall back into the ocean to be retrieved, refurbished, and prepared for another flight. After the solid rocket boosters are jettisoned, the orbiter's three main engines, fed by the external tank, continue to provide thrust for another six minutes before they are shut down, at which time the giant tank is jettisoned and falls back to Earth, disintegrating in the atmosphere.

The Space Shuttle Orbiter

The orbiter is both the brains and heart of the Space Transportation System. Advanced technology was created for the vehicle in such areas as flight control, thermal protection, and liquid-rocket propulsion. About the same size and weight as a DC-9 aircraft, the orbiter contains the pressurized crew compartment (which can normally carry up to seven crew members), the huge cargo bay, and the three main engines mounted on its aft end. The

Launch and landing sequence for all Shuttle missions–past, present, and future



thermal tile system, which protects the orbiter during its searing reentry through the atmosphere, was one breakthrough technology that proved much more challenging than expected.

There are three levels to the crew cabin. Uppermost is the flight deck where the commander and pilot control the mission, surrounded by an array of switches and controls. During launch of a seven-member crew, two other astronauts are positioned on the flight deck behind the commander and pilot. The three other crew members are in launch positions in the mid-deck, which is below the flight deck.

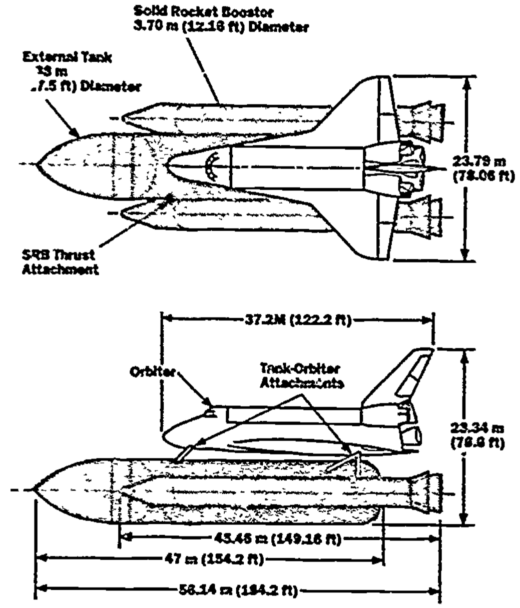
The mid-deck is where the galley, toilet (no shower in the Space Shuttle as there was in Skylab), sleep stations, and storage and experiment lockers are found—the basic needs for weightless, daily living. Also located in the mid-deck are the side hatch for passage to and from the vehicle before and after landing, and the airlock hatch into the cargo bay and space beyond. It is through this hatch and airlock that astronauts go to don their spacesuits and manned maneuvering units (MMU's) and prepare for extravehicular activities (EVAs), more popularly known as "spacewalks." These excursions have produced some of the most important space firsts in the Shuttle program as well as the most spectacular photographic vistas of the Space Age. Below the mid-deck's floor is a utility area for the air and water tanks and their ducts.

The Space Shuttle's cargo bay is adaptable to hundreds of tasks. Large enough to accommodate a tour bus 18.28 x 4.57 meters (60 x 15 feet) the cargo bay instead carries satellites, spacecraft, and Spacelab scientific laboratories to and from Earth orbit. It is also a work station for astronauts to repair satellites, a foundation from which to erect space structures, and a hold for retrieved satellites to be returned to Earth.

Mounted on the port side of the cargo bay behind the crew quarters is the remote manipulator system (RMS), developed and funded by the Canadian government. The RMS is a robot arm and hand with three joints analogous to those of the human shoulder, elbow, and wrist. Two TV cameras mounted near its elbow and wrist provide visual cues to the crew member who operates it from the aft station of the orbiter's flight deck. The RMS

The flight deck of Space Shuttle *Columbia*, contains an array of controls and switches. The commander's position is on the left and the pilot sits on the right. The three CRT screens in the center display computer data and other essential information.

The Space Shuttle's cargo bay is large enough to hold several satellites or a pressurized Spacelab module for a scientific team. On this maiden *Challenger* mission in 1983, the first Tracking and Data Relay Satellite (TDRS-A), booster attached, was deployed. Its hold-down ring and other support equipment was left behind and will be used again.



(about 15 meters [50 feet] in length) can move anything from satellites to astronauts to and from the cargo bay or to different points in nearby space. It has served with distinction on many missions, deploying and retrieving various scientific and communications satellites.

Thermal tile insulation and blankets (also known as the thermal protection system or TPS) covers the underbelly, bottom of the wings, and other heat-bearing surfaces of the orbiter and protects it during its fiery reentry into the Earth's atmosphere. The tiles represent another new technology that will continue to serve future spacecraft of the 21st century.

In contrast to earlier manned spacecraft such as the *Apollo* command module, which used ablative material that burned and melted off in layers during reentry heating and could never be used again, the Shuttle's silicate fiber tiles were invented and designed to be used for 100 missions before replacement is necessary.

Some 24,000 individual tiles—no two alike—must be installed by hand on the orbiter's surfaces. The basic material of the tiles is pure-sand silicate fibers, mixed with a ceramic binder. The tiles are incredibly lightweight, about the density of balsa wood, and dissipate the heat so quickly that a white-hot tile with a temperature of 1,260 degrees Celsius (2,300 degrees Fahrenheit) can be taken from an oven and held in bare hands without injury.

The Main Engines and Secondary Propulsion Systems

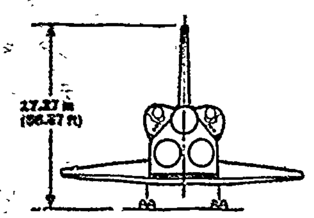
The three main engines are clustered at the aft end of the orbiter and have a combined thrust of almost 544,308 kilograms (1.2 million pounds) at sea level. Another example of breakthrough technology on the orbiter, they are high-performance, liquid-propellant rocket engines whose thrust can be varied over a range of 65 to 109 percent of their rated power level. They are the world's first reusable rocket engines and are designed for seven and one-half hours of operation. Because they fire for eight minutes for each flight to orbit, the current engines are designed to operate for 55 flights. A person would be dwarfed if he stood next to a main engine. They are 4.2 meters (14 feet) long and 2.4 meters (8 feet) in diameter at the nozzle exit.

Another propulsion system takes over once the Space Shuttle's main engines shut down as the ship approaches orbital insertion. Two orbital maneuvering system (OMS) engines, mounted on either side of the aft fuselage, provide thrust for major orbital changes. For more exacting motions in orbit, forty-four small rocket engines, clustered on the Shuttle's nose and on either side of the tail, are used. Together they are known as the reaction control system and have proven indispensable in doing the Shuttle's important work of retrieving, launching, and repairing satellites in orbit.

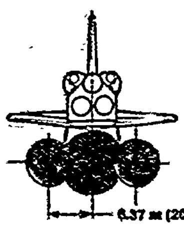
The External Tank

This giant cylinder, higher than a 15-story building, with a length of 47 meters (154 feet) and as wide as a feed silo with a diameter of 8.4 meters (27.5 feet), is the largest single piece of the Space Shuttle. During launch the external tank also acts as a backbone for the orbiter and solid rocket boosters to which it is attached.

In separate pressurized tank sections inside, the external tank holds the liquid hydrogen fuel and liquid oxygen oxidizer for the Shuttle's three main engines. During launch the external tank feeds the fuel under pressure through 43.18-centimeter (17-inch) ducts which branch off into smaller lines that feed directly into the main engines. Some 242,260 liters (64,000 gallons) of fuel are consumed by the main engines each minute.



Basic dimensions of the Space Transportation System for its launch and early flight configuration.



The versatile robot arm, the remote manipulator system, can move satellites, astronauts, or other payloads. Here Bruce McCandless tests its use as a "cherry-picker" while secured to the foot restraint attachment on a *Challenger* mission in February 1984.

Machined from aluminum alloys, the Space Shuttle's external tank is the only part of the launch vehicle that currently is not reused. After its 1,991,126 liters (526,000 gallons) of fuel are consumed during the first eight and one-half minutes of flight, it is jettisoned from the orbiter and breaks up in the upper atmosphere, its pieces falling into remote ocean waters.

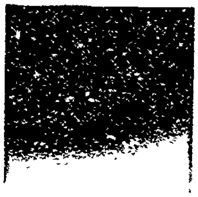
The Solid Rocket Boosters

Like giant roman candles on either side of the Space Shuttle orbiter, these solid-fuel rockets represent the most traditional and time-tested technology of the major Shuttle components. But even though the basic solid-fuel technology had proven itself over two decades in Air Force programs, the hardware failure of the joint and O-ring seal of one of the solid boosters was the primary cause of the *Challenger* loss. With rigorous testing during the recovery program, including flaws deliberately built into the test boosters, the new joint design passed stringent examination and review.

The Space Shuttle's two solid-rocket boosters, the first designed for refurbishment and reuse, are also the largest solids ever built and the first to be flown on a manned spacecraft. Together they provide the majority of thrust for the first 2 minutes of flight—some 2,630,822 kilograms (5.8 million pounds).

The solid propellant mix is composed of 16 percent aluminum powder (fuel) and almost 70 percent ammonium perchlorate (oxidizer), with the remainder made up of a binder, a curing agent, and a small amount of catalyst. A small rocket motor in each booster ignites the propellant at launch.

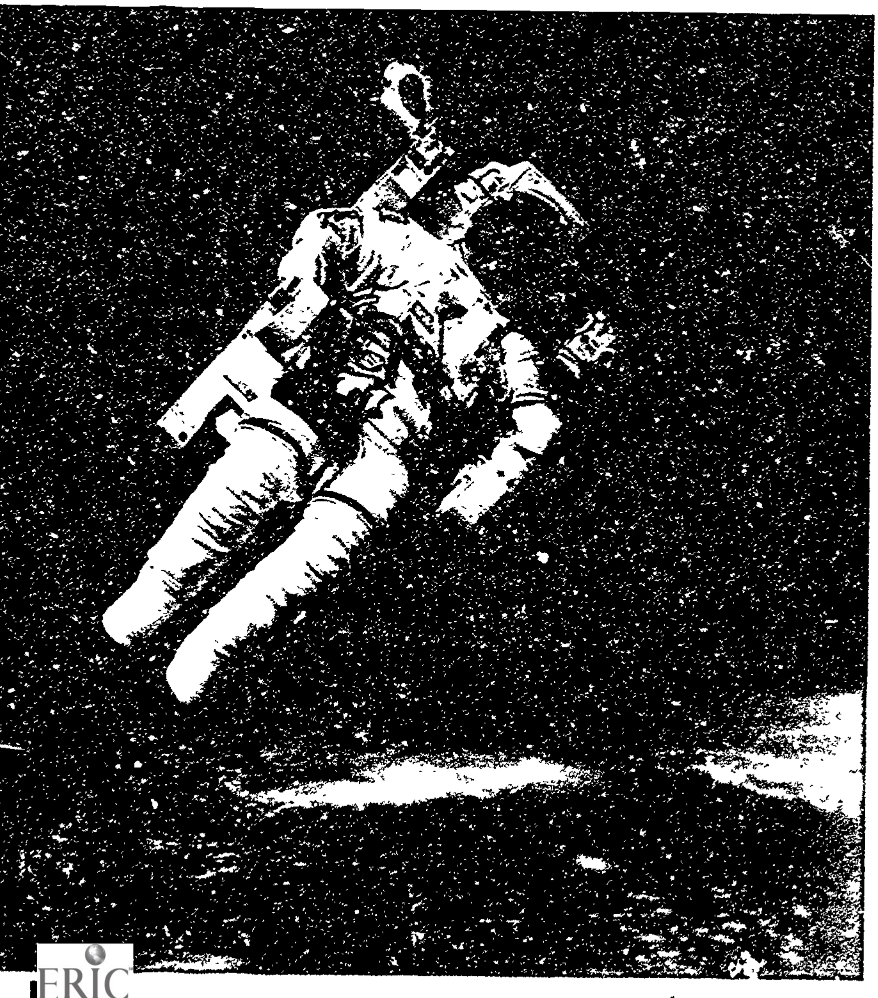
During flight the solid booster nozzles swivel up to six degrees, redirecting the thrust and steering the Space Shuttle toward orbit.



Below Left:
Bruce McCandless took the world's first untethered spacewalk while strapped into the manned maneuvering unit during the *Challenger* mission in February 1984.
Right:
Crewmate Robert Stewart became the second man in the world to fly free and see the best view of Earth.

Versatile Achievements

The First Twenty-four Flights



There are enough Space Age firsts and standing records established during the first 24 Shuttle flights to fill an almanac. Dozens of commercial, scientific, and military satellites were delivered to orbit; two were retrieved and brought back to Earth; and two were plucked out of orbit, repaired in the Shuttle's cargo bay, and put back to work, one studying the Sun and the other providing communications services.

Each time a Space Shuttle flew, it became a temporary station in space. Each time a crew blasted to orbit, the spacecraft became a valuable life sciences laboratory from which new data was collected on how the body responds to weightlessness. The Shuttles also became temporary construction bases from which solar panels were unfurled and tested and components of future space structures erected and tested by astronauts in their flying MMUs.

When the first four Spacelabs flew inside Shuttle cargo bays during missions in 1983 and 1985, each with its own scientists and program of experiments, the amount of data generated was astonishing. Spacelab 1, the first operational mission of the European-built laboratory, flew on *Columbia* in late 1983. More than 70 experiments were conducted, and 200 investigators from 16 countries participated in activities carried out during the flight. The 1985 flight of Spacelab 3, nicknamed the "flying zoo" because it flew two monkeys and twenty-four rats on board, collected some 250 billion bits of computer data—enough to fill 50,000 books of 200 pages each if converted into words.

Some 125 crew positions were flown on the first 24 missions. Most of the commanders flew more than once, with Robert L. Crippen holding the record of four Space Shuttle

missions, one as pilot and three as commander. A total of 19,970 crew hours were accumulated, or more than two and one-fourth years of total Shuttle crew experience. The Shuttle fleet also flew more than 338,833.5 kilograms (747,000 pounds) of cargo to orbit, of which almost 136,077.7 kilograms (300,000 pounds) were deployed into space.

Cargoes of Satellites

Orbiting satellites are the gold ingots of an information age, and the Shuttles have delivered over two dozen of them to serve planet Earth.

A single mission of *Discovery* (51-G) that flew in June 1985 carried four satellites (three of which were for communications) in its cargo bay and deployed them in orbit: Morelos-1 for Mexico; Arabsat 1-B for the Arab Satellite Communications Organization; Telstar 3-D for AT&T; and *Spartan* 1, an astronomical satellite which gathered data on mysterious X-ray sources in our Milky Way galaxy and which was retrieved later in the mission and brought back to Earth.

Three other mission accomplishments involving satellites, while important in their own right, are more significant in what they promise for the future.

In April 1984, the *Challenger* rendezvoused in orbit with the ailing Solar Maximum scientific satellite, which had been drifting uselessly in orbit for three years because of three blown fuses in its attitude control box. The mission plan was to retrieve Solar Max, anchor it in the cargo bay, repair it with new modular components, and send it back to work in orbit.

A selected list of important Space Shuttle accomplishments and records of the first 24 missions appear in the table on the following page.

The happy crew of *Columbia* on STS-5, the first mission after four orbital test flights. This was the first time two commercial satellites were deployed from the Shuttle. Commander Vance Brand holds sign, surrounded by (clockwise) William Lenoir, Robert Overmyer, and Joseph Allen.

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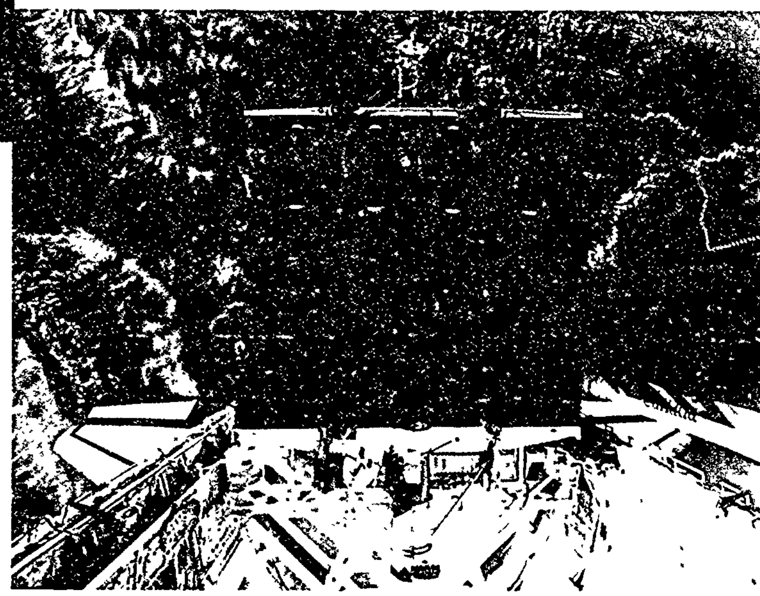
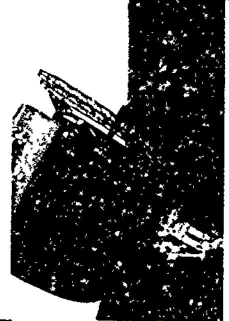
Left:
Artist's view of the fully extended array, which extended 32 meters (105 feet) and became the largest structure ever deployed from a spacecraft.



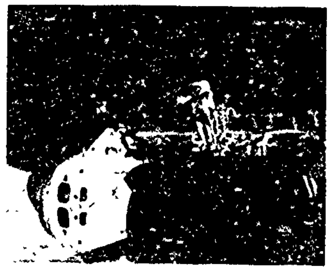
Right:
The raising of an experimental solar array on *Discovery's* maiden flight (August/September 1984) proved that similar systems would work for future space facilities and stations. It was deployed by mission specialist Judith Resnik from the control station at the aft of the flight deck.

Selected Space Shuttle Mission Achievements and Firsts

Launch Date	Orbiter and Mission	Mission Achievements and Firsts
4/12/81	*Columbia (STS-1)*	First orbital flight test of the Space Shuttle; heaviest manned spacecraft
11/12/81	*Columbia (STS-2)*	First time manned spacecraft flies second mission to orbit
11/11/82	*Columbia (STS-5)*	First deployment of commercial satellites (two) by Shuttle
4/4/83	*Challenger (STS-6)*	First made-in-space product, microscopic latex spheres, for use in scientific calibration
6/18/83	*Challenger (STS 7)*	First use of robotic arm remote manipulator system (RMS) to deploy and retrieve satellite (Shuttle Pallet Satellite, SPAS); first American woman in space, Sally K. Ride
8/30/83	*Challenger (STS-8)*	First Shuttle night launch and landing, first black American in space, Guion S. Bluford, Jr.
11/28/83	*Columbia (STS-9)*	First flight of *Spacelab*, with 71 scientific investigations (U.S. and European)
2/3/84	*Challenger (41-B)*	First untethered "spacewalk" and use of manned maneuvering unit (MMU) by Bruce McCandless; first Shuttle landing at Kennedy Space Center, Florida
4/6/84	*Challenger (41-C)*	First repair of satellite in orbit (Solar Maximum satellite)
8/30/84	*Discovery (41 D)*	First deployment and testing of huge solar array panel by Judith Resnik, first commercial payload specialist, Charles D. Walker
10/5/84	*Challenger (41-G)*	First seven-person crew; first American woman to walk in space, Kathryn D. Sullivan
11/8/84	*Discovery (51-A)*	First retrieval of satellites in orbit, Palapa B-2 and Westar VI and their return to Earth
6/17/85	*Discovery (51-G)*	First time four satellites were launched from Shuttle, first laser test, 100th American in space
8/27/85	*Discovery (51-I)*	Record EVA time of over 7 hours to repair Leasat (*Syncom IV-3*), first human "launch" of satellite by James "Ox" van Hoften
11/26/85	*Atlantis (61-B)*	First assembly of structure in space (a 14 meter [45-foot] beam tower) during EVA to test building techniques for future Space Station
1/12/86	*Columbia (61-C)*	First verification flight of Hitchhiker carrier, with 3 experiments



After capturing and repairing the huge, 7.5 ton Syncom IV communications satellite in *Discovery's* cargo bay (August/September 1985), astronaut James van Hoften gave Syncom a spin and arm-launched it from his perch on the RMS robot arm. Note the Moon below the Earth, next to the antenna.

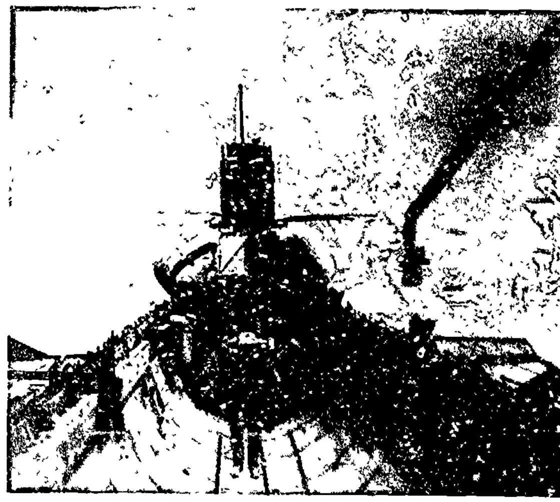


From the robot arm, van Hoften took this photo of his fellow spacewalker, William Fisher, anchored to a foot restraint on the far side of the cargo bay.

While this was eventually done, the entire mission plan had to be rewritten because the latch device built for the astronauts did not work with the mate hardware on the satellite. After several unsuccessful attempts, the *Challenger* and its RMS robot arm snagged the satellite and the $235 million Solar Max was repaired and returned to work. This mission success is a prime example of the versatility of the Shuttle and its crew and demonstrates how trained astronauts and expert ground support can succeed where hardware alone would fail.

A second satellite repair in orbit occurred during a *Discovery* mission in August 1985. The 6,803.8 kilogram (7.5 ton) Syncom IV, deployed on an earlier mission in April, was not working because of a failed sequencer. Astronauts James van Hoften and William Fisher brought the huge satellite into the cargo bay and began repairs to bypass the defective sequencer. This became a record-breaking EVA of 7 hours, 8 minutes. The next day the astronauts manually struggled to align the unwieldy satellite for its return to orbit. Standing on the work platform of the RMS robot arm and holding the bulky Syncom, astronaut van Hoften rose up from the cargo bay. With several pushes of a bar, he gave the satellite its needed spin of three revolutions per minute, and it went spinning into space. This was the world's first hand-launched satellite. An $85 million satellite had been saved.

In November of 1984, Shuttle *Discovery* also became the world's first spaceship to retrieve satellites and return them to Earth. Western Union's Westar VI and Indonesia's Palapa B-2 were successfully launched from the *Challenger* in February 1984. Shortly after deployment, their built in rocket motors, which would have taken them to higher

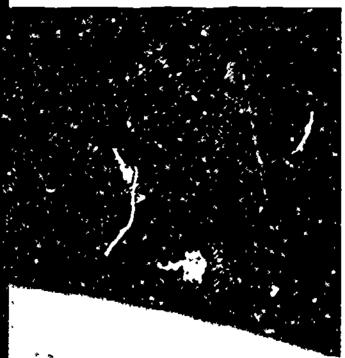


orbits failed. Had it not been for this space salvage operation, two sophisticated communications satellites, with a combined worth of about $70 million, would have been written off.

Astronauts Joseph Allen and Dale Gardner did the EVA retrieval work by using a specially designed tool, nicknamed the "stinger," to maneuver the satellites within reach of the RMS robot arm, which then would move them into the cargo bay. But a problem came up when they were retrieving the Palapa. An unanticipated protrusion made it impossible to use a securing bracket. The astronauts improvised. Allen stood on the end of the remote arm, his feet in foot restraints, and held the satellite with his arms while Gardner clamped it down in the cargo bay. This procedure took a complete orbit, and astronaut Allen held the satellite above his head for an entire trip around the world. *Discovery* and its cargo of two satellites landed on runway 33 at the Kennedy Space Center after a mission just minutes short of eight days.

Above Left:
Secured in the aft of the cargo bay, the Solar Maximum Mission Satellite became the first satellite to be repaired in Earth orbit. It was, however, a more difficult task than expected to nab Solar Max and get it into the cargo bay. Good piloting and the RMS robot arm saved the day.

Above:
Challenger's Solar Max repair crew of April 1984 gathered on the flight deck for this good-humored portrait. Through the window is the cargo bay. Left to right: Francis (Dick) Scobee, George Nelson, James van Hoften, Terry Hart, and Commander Robert Crippen.



Flying free over the Bahama Banks in November 1984, astronaut Dale Gardner approaches the Westar VI satellite with his "stinger" tool to begin retrieval and salvage operations.

After attaching the stinger to Westar, Gardner maneuvers the satellite over to the RMS robot arm.

Sally Ride, America's first woman in space, monitors the continuous flow electrophoresis unit (CFES) on *Challenger's* mid-deck in June 1983. Large quantities of biological substances are purified in space with this process, which promises to produce breakthrough drugs and medicines.

Commerce and Science in Orbit

The first commercial experiment took place on the fourth Space Shuttle mission in late June and early July 1982. Called the continuous flow electrophoresis system, it was built to purify biological materials in a microgravity environment and flew on a total of seven missions. After several astronauts monitored the equipment on three flights, Charles Walker became the first commercial payload specialist to fly in space on a *Discovery* mission in 1984. He tended the system again on two other missions, in April and November 1985.

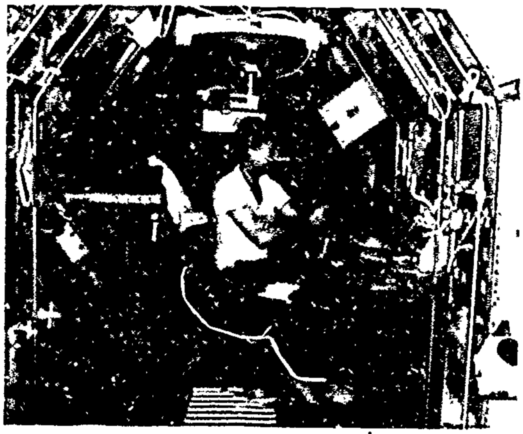
The experiments demonstrated that some seven hundred times more material can be separated in space than on Earth during the same period, and purity levels are better. The process holds great promise for breakthrough drugs and medicines that could eventually save tens of thousands of lives and offer new treatments to millions of people suffering from diseases such as diabetes and hemophilia

The first made-in-space product was manufactured on a *Challenger* mission in April 1983 and went into the marketplace in 1985. Slightly larger than a red blood cell and invisible to the human eye, the product consists of tiny microscopic spheres made of polystyrene sold in lots of 30 million by the National Bureau of Standards. The microgravity of the Shuttle had allowed these spheres to grow more uniformly in size and shape than is possible on Earth. Customers use the spheres to help calibrate and focus electron microscopes and to improve microscopic measurements in electronics, medicine, environmental pollution research, and other high-technology areas. Each lot of 30 million comes in a small vial filled mostly with water.

Crystal-growth experiments on Shuttle flights have demonstrated that the manufacture of crystals in microgravity has tremendous industrial potential. Crystals grown in orbit have fewer imperfections and therefore improved electronic characteristics. Experts believe that such crystals may lead to a new generation of higher-speed microelectronic components for computers, radar, and communications systems.

During the *Spacelab* 1 mission in November and December 1983, one type of protein crystal grew 1,000 times larger than the same type did on Earth. Such large protein crystals allow bioengineers to study the atomic structures of protein molecules—knowledge they must have in designing new drugs. The molecular models derived from such space-grown crystals may well be the foundation for the new miracle drugs of the 21st century.

By the early 1990s, the long-awaited Hubble Space Telescope will have brought never-before-seen cosmic vistas down to Earth for all to see, and astronomers will have a new universe to ponder. Launching this giant telescope could be the most important astronomical event since Galileo pointed his small telescope toward the Moon and planets more than 375 years ago. Weighing some 11,567 kilograms (25,000 pounds) and measuring 13.1 by 4.3 meters (43.1 by 14.1 feet), the Hubble will fill most of the cargo bay. This made-for-space telescope is the most powerful, complicated, and precise astronomical instrument ever built. It may do nothing less than revolutionize astronomy during its projected operational life of fifteen to twenty years.



The *Spacelab* 1 scientific module flew in *Columbia's* cargo bay in November/December 1983 and was the first operational mission of the European-built laboratory. More than 70 experiments were conducted, including one where a protein crystal grew 1,000 times larger than it could on Earth. Astronauts Owen Garriott and Byron Lichtenberg are working in the lab.

The Hubble Space Telescope will be able to observe objects far fainter than those visible to the most powerful telescopes on Earth. During its first decade in orbit, the Hubble will focus on the cosmic puzzles of the black holes, exploding galaxies, and quasars, and solve or shed light on their mysteries. It will, in effect, be peering farther into the universe and farther back in time than ever before, allowing scientists to construct a more accurate history of our universe.

Student participation in space science projects will take on new meaning when the Space Shuttle retrieves from orbit the Long Duration Exposure Facility and brings its experiments back to Earth. Placed into orbit by the *Challenger* in April 1984, the large unmanned scientific laboratory takes up one-half the cargo bay. Originally scheduled to be retrieved in 1986, it was delayed for several years.

One experiment contains 12.5 million tomato seeds packaged in Dacron bags and sealed in aluminum canisters. On their return to Earth, these seeds will be put into thousands of laboratory kits, along with control seeds that remained on Earth, and sent to schools across the nation. As many as 1 million elementary, secondary, and university students will participate in designing their own experiments and studying the seeds by comparing germination rates, seed embryos, and fruit products. With such wide participation of the nation's youth, this program will literally be planting some seedlings for future space science.

Unmanned interplanetary spacecraft will make their distant encounters a few years later than originally planned. The *Magellan* radar mapping mission to Venus and the *Galileo* mission to Jupiter, which will send a probe into the giant planet's thick atmosphere and orbit it for two years, are precious scientific cargoes for the Shuttles.

In the early 1990s, the Mars Observer will begin its journey to the Red Planet and upon arrival conduct a detailed study of its surface and atmosphere. Many other unmanned spacecraft missions are fighting for a place in the Sun during a time of federal budget constraints, including a project called *Cassini*, which may orbit Saturn's mysterious moon Titan and send a probe through its thick atmosphere before the year 2000. The Shuttle fleet will guide some of them out of Earth's harbor and into open space as they cast off for their distant planetary destinations.

Placed in orbit by Space Shuttle *Challenger* in April 1984, the Long Duration Exposure Facility will be brought back to Earth on a future Shuttle mission. One experiment contains 12.5 million tomato seeds which, when retrieved, will be distributed to as many as 1 million students across the United States who will conduct experiments.

Bottom Left:
Built up from a base in the *Atlantis* cargo bay, this trusswork tower was erected to demonstrate assembly techniques in orbit that will be important to future space stations and other facilities. Astronaut Sherwood Spring checks the joints on the assembly during the November 1985 mission.

The Space Shuttle Into the 21st Century

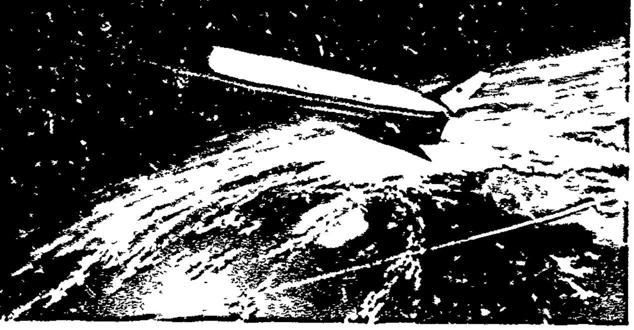
The Space Shuttle fleet will remain the foundation of America's manned space program into the new century. When the new orbiter joins *Atlantis*, *Columbia*, and *Discovery* in the 1990s, the National Space Transportation System will be able to fly 12 to 14 missions a year if the ground support system is adequate. One hundred or more Shuttle missions in the last decade of the 20th century is likely, and some orbiters may continue to fly until 2005 and perhaps 2010.

More Time and Space for Shuttle

For future flights, plans are under review by NASA to extend the mission times up to 16 days by supplementing the systems on the orbiter. This would be done by using a portion of the cargo bay to hold additional fuel cells and low temperature storage tanks for oxygen and hydrogen reactants. Other design upgrades would be made on the carbon dioxide removal and the waste management systems.

The future benefits of keeping the Space Shuttles in orbit longer could be substantial. By extending some missions to 16 days, the science return on dedicated research missions could be more than two times that of the usual seven-day flights. Longer duration missions for such disciplines as life science and microgravity research would significantly reduce the backlog of scientific investigations.

An increase in the Shuttle's living and working space is also planned. A private U.S. company has designed an add-on module called Spacehab that can fit in the forward cargo bay behind the crew quarters. The crew would enter Spacehab from the mid deck through a tunnel adapter similar to that used for the scientific Spacelab module. Spacehab would



A spaceplane of the 21st century, powered by an air-breathing hydrogen-fueled engine, may represent the next generation of space vehicle after the Space Shuttle. It would take off horizontally like a traditional aircraft.

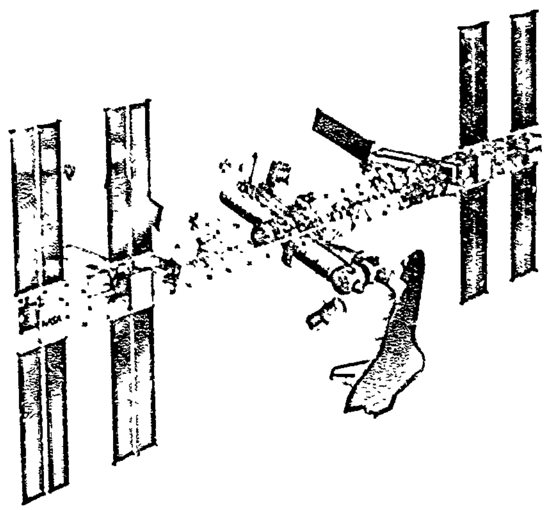
add 28 cubic meters (1000 cubic feet) of working and storage space to the 71.5 cubic meters (2525 cubic feet) available in the crew cabin.

A Station in Space

After evolving through a series of designs in the 1980s to better serve a complex of user needs and adapt to restraints in the federal budget, the Space Station (named *Freedom* by President Reagan in July 1988) depends heavily on the Space Shuttle fleet to put it in orbit before the turn of the century.

As currently envisioned, the Space Station *Freedom* will be a permanently manned orbiting research laboratory by the end of the century. It will have four large pressurized modules clustered in the middle of a 155-meter (508-foot) trusswork boom, with two pairs of rectangular solar arrays attached to each end to supply electrical energy. One module will be the habitat containing the galley, sleeping quarters, and bathroom facilities, where scientists and astronauts will live and relax. The other three modules will be laboratories (life sciences and materials sciences, for example) of the United States, Europe, and Japan. Another component of the station will be the Canadian Mobile Servicing Center.

The value of the *Freedom* Station is its utility for the 21st century—the future which will soon be upon us. The Station's state-of-the-art research will create technological breakthroughs in the medical, physical, and other sciences, which will eventually be transferred into benefits for tens of millions of people around the world. While some benefits may become apparent during the first year of operation in orbit, many technology spinoffs



An artist's concept of a permanently manned U.S. space station shows cluster of habitat and laboratory modules at center. The Space Shuttle, docked at one end, will bring up new crews and resupply consumables.

may take as long as a decade to make the technology transfer and influence our daily lives. In addition the station ultimately will serve as a way station to the worlds beyond—for missions to the Moon and Mars, for example.

One study scenario estimates the need for some 20 Space Shuttle flights, beginning in 1995 and ending in 1998, to launch *Freedom's* components for construction and complete the facility. This mission sequence could change if unmanned, expendable rockets were also used to supplement the Shuttle cargoes. But whatever the final mix of launch vehicles and whatever the final timetable, an orbiting station in space will realize the visions of early space pioneers who knew it was possible and predicted, early in the 20th century, how such an outpost in space could serve the people of planet Earth.

The first Space Shuttle crew since the *Challenger* breaks from training for *Discovery's* STS-26 mission to pose for this informal portrait. All Shuttle flight veterans, they are (left to right): David (Dave) Hilmers, Frederick (Rick) Hauck (Commander), Richard (Dick) Covey, John (Mike) Lounge, and George (Pinky) Nelson.

Shuttle's Offspring

What happens when the last Space Shuttle mission has flown early in the 2000s and the fleet is finally retired and Earthbound? What future spaceships will follow the Shuttles?

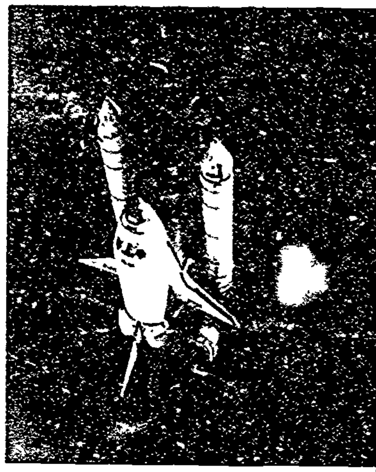
There may be a new fleet of spaceplanes in the first few decades of the next century. Research already underway, much of which is conducted on the world's most advanced computers, will make possible second-generation spaceplanes that could travel frequently to and from Earth orbit powered by advanced, air-breathing scramjet engines. These powerful engines would ingest oxygen as they ascend through the atmosphere, thus saving a tremendous amount of launch weight on fuel.

Such spaceplanes could take off horizontally from conventional runways and then accelerate directly to orbit as a single-stage-to-space craft. Without strapped-on solid boosters or external tanks, they could ascend to the upper reaches of the atmosphere before rockets kick in for their final power drive to orbit. Unlike today's Shuttle, which drops like an unpowered glider to Earth, spaceplanes would be capable of controlled descent and land at most conventional airports. Space could be more accessible than ever before to larger numbers of people If these successors to the Shuttle become reality, the original Shuttle orbiters may be thought of as the DC-3s of the early Space Age.

NASA celebrated its 30th anniversary in 1988, two days after the Space Shuttle soared into space once more. When Congress approved the creation of the National Aeronautics and Space Administration in 1958, the United States had successfully launched only four small satellites and no American astronaut had yet flown in space. In the three decades since, four generations of manned spacecraft have been built and flown, twelve men have walked on the Moon, more than 100 Americans have flown and worked in space, and communications satellites and other Space-Age technologies have transformed life on planet Earth.

When NASA's Golden Anniversary is celebrated in 2008, it is likely that men and women will be permanently living and working in space. There may be a base on the Moon, and a manned mission to Mars may only be years away. If a brief history of the first half-century of the Space Age is written for that event, it will show clearly how the exploration of space has altered the course of human history and allowed us to take a better hold of our destiny on and off planet Earth.

The Space Shuttles, their crews, and the thousands of men and women dedicated to making their journeys to space successful are doing nothing less than helping create a better future. It is with such dedication that all will enter the 21st century and realize the full promise of space.



Above:
View from above. Space Shuttle *Discovery* begins its journey to launch pad 39B from the Vehicle Assembly Building (VAB) on July 4, 1988

Right:
Discovery nears the launch pad during roll out for the historic STS-26 return-to-flight 'aunch on September 29, 1988.